CALCULATIONS OF FUSE SHARPENED EXPLOSIVE MAGNETIC FLUX COMPRESSION GENERATOR DISCHARGES INTO HIGHER IMPEDANCE LOADS

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Numerical calculations of fuse sharpened explosive magnetic flux compression generator discharges into high impedance loads are presented and discussed. The explosive generator analog[1] of the Maisonnier capacitor driven fuse criteria[2] were used to obtain estimates of optimum fuse cross sections. The initial fuse cross section is chosen so that the specific energy of the fuse produced by resistive heating just reaches the onset of vaporization at the time of peak current in the absence of a fuse. The fuse cross sections were varied in the region of that estimated optimum. Generator inductance per unit length was chosen so that the time rate of change of the (end initiated helical) generator inductance is comparable to the load resistance[3]. An inductance in series with the load was varied to adjust the load voltage pulse width[4]. The fuse length (1 meter) was chosen to be in the range where the resistive energy deposited in the fuse is comparable to that required to just fully vaporize the fuse. The calculated performance for those parameters for which the predicted fuse voltage per unit length is less than 10 kilovolts/cm can be considered credible. These calculations suggest that voltage pulses of several tenths of megavolts with several tenths of microsecond full width at half maximum for several ohm loads are achievable by this approach.

CIRCUIT DESCRIPTION AND ITERATION EQUATIONS

The circuit, illustrated in Fig 1, is two loops, with the first loop including an EMG inductance L_g, a series resistance R_g, a series inductance L_s, a fuse resistance R_f, a fuse inductance L_f. The fuse effective resistivity is a piecewise continuous fit to $\rho(e)$, where $e = (\int I_f R_f\, dt)/m_f$, I_f is the fuse current, and m_f is the fuse mass. The second loop includes a closure switch (initially open, triggered by the fuse voltage exceeding a threshhold), a load resistance R_L, and load inductance L_L. The second loop is in parallel with the fuse. The loop currents are I_1, (EMG loop) and I_2 (the load loop). The fuse current is $I_f = I_1 - I_2 = I_1$ before the closure switch is triggered. Before closure switch triggering

$$\frac{d}{dt}\left(I_1(L_g + L_s + L_f)\right) + I_1(R_g + R_f) = 0 \qquad (1)$$

$$\frac{dI_1}{dt} = -I_1\left(\frac{dL_g}{dt} + R_g + R_f\right)/(L_g + L_s + L_f) \qquad (2)$$

where $R_l=\rho_f(x/s)$, ρ_f = fuse resistivity = function of $e=(\int I_f R_f\, dt)/m_f$, and the other elements are fixed.

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14. ABSTRACT
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After closure switch triggering

$$\frac{dI_1}{dt}(L_g + L_s + L_f) + I_1\left(\frac{dL_g}{dt} + R_g + R_f\right) - I_2R_f - \frac{dI_2}{dt}L_f = 0 \quad (3)$$

$$I_2R_L + \frac{dI_2}{dt}L_L + I_2R_f + \frac{dI_2}{dt}L_f - I_1R_f - \frac{dI_1}{dt}L_f = 0 \quad (4)$$

From (3) and (4) one readily obtains the iteration equations

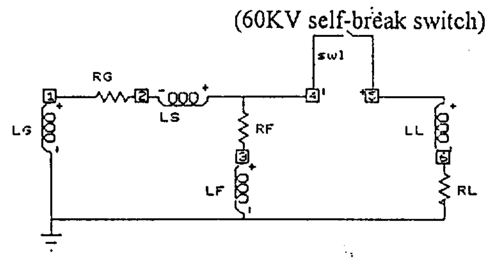
$$\frac{dI_2}{dt} = \left[- I_2R_L - \frac{dI_1}{dt}(L_g + L_s) - \frac{dI_1}{dt}(L_g + R_g)\right]/L_L \quad (5)$$

$$\frac{dI_1}{dt} = \left[- \frac{dI_1}{dt}\left(\frac{dL_g}{dt} + R_g + R_f\right) + I_2R_f + \frac{dI_2}{dt}L_f\right]/(L_g + L_s + L_f) \quad (6)$$

Results and comments

Using the Al fuse resistivity vs specific energy illustrated in Fig 2, calculations of fuse sharpened explosive generators were done. This resistivity vs specific energy has worked well in modeling capacitor driven, fuse opening switch inductive store experiments at our laboratory, in which the fuse was made from 1 mil (2.54 x 10^{-3} cm) thick Al foil embedded in BT-12 glass blasting beads. Selected results are summarized in Table I and Fig 3. In these calculations, the fuse cross section S_f was chosen by using the explosive generator analog of the Maisonnier analytic optimum (cf Fig 1), for nonadiabatic parameter k_2 = 1 and 2. A zero fuse resistance calculation of the current in the first circuit loop is done prior to determining the fuse cross section. The fuse length was 1 meter.

The selected calculations explore the suggestions by Kiuttu[3] to use a generator with a large dL_g/dt (comparable to the load resistance), and by Chase[4] to use a larger inductance in series with the load to lengthen the voltage pulse. The load resistance for these calculations was 4 ohms. These calculations suggest that voltage pulses of several tenths of megavolts with several tenths of microsecond full width at half maximum for several ohm loads are achievable by this approach. Varying the (constant) generator resistance in the 50 to 200 milliohm range has little effect. A time varying resistance would be more realistic, but it would be in this range. In creasing the inductance in series with the load resistance has the expected effect of increasing the fuse and load voltage pulse widths. Note that the load (I_2) current for the 4 ohm load is essntially proportional to the load voltage. Use of the k_2=1 choice of fuse cross section results in predicted fuse voltages of approximately 600 KV, or fields of approximately 6 KV/cm, which is credible for such fuses.



$L_g = L_{go}(1 - (t/t_{fct}))$, $0 < t < t_{fct}$

$= 0$, $t > t_{fct}$

$t_{fct} = 50\ \mu sec$

$L_s \sim 0.01\ L_{go}$

$L_f = 10$ nanohenries

$R_f = \rho_f (x_f/s_f)$

$\rho f =$ fct of $\int I_f^2 R_f dt/m_f$

$m_f = v_f x_f s_f$, $v_f = 2.7 \times 10^3\ kg/m^3$ (Al)

$x_f = 1.0$ meter

$S_f \approx \left(\int^{50\ \mu sec} I_1^2 dt/k_2 \int \rho^{-1} d\epsilon\right)^{1/2}$

$\int \rho^{-1} d\epsilon = 4.9 \times 10^{16}$(mks) (Al)

$k_2 = 1$ to 2 = nonadiabatic parameter

$R_L = 4\ \Omega$

Fig.1 Explosive magnetic flux compression generator - fuse circuit and element definition.

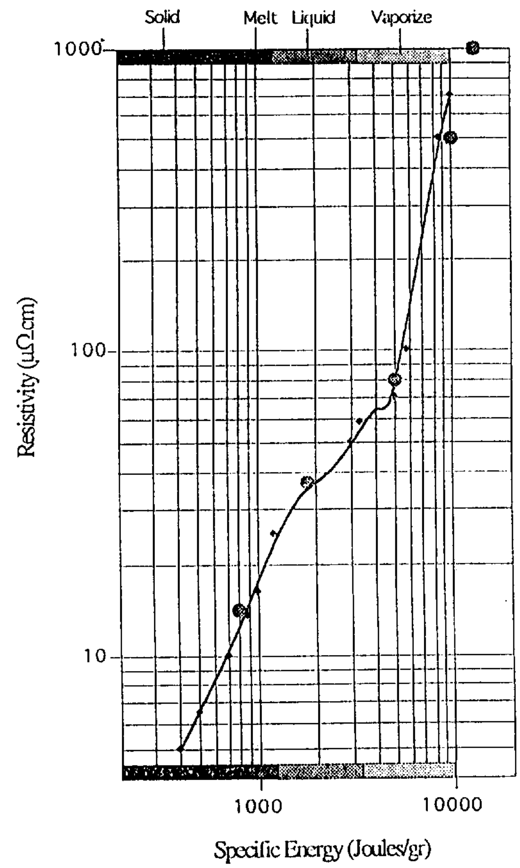
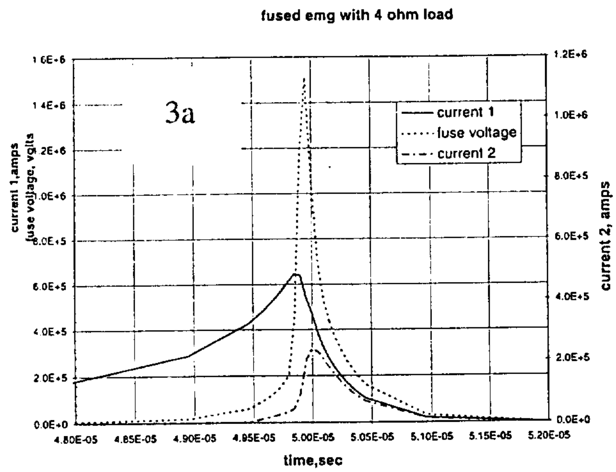
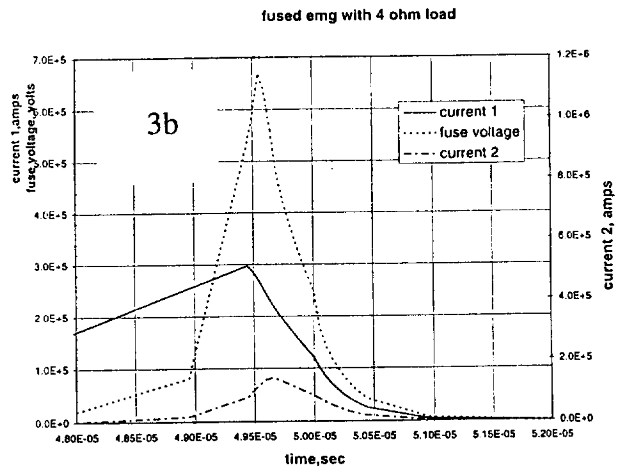
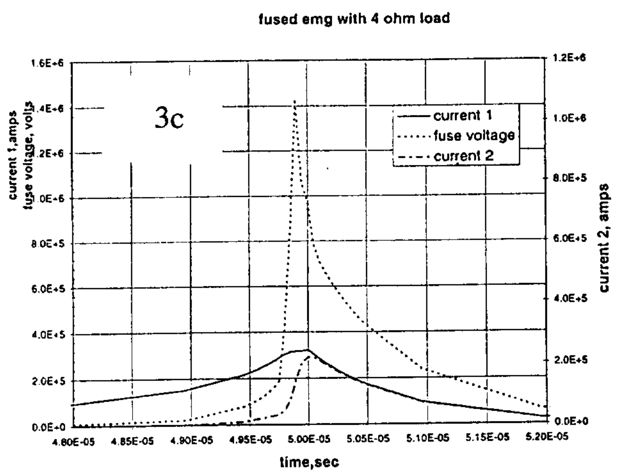
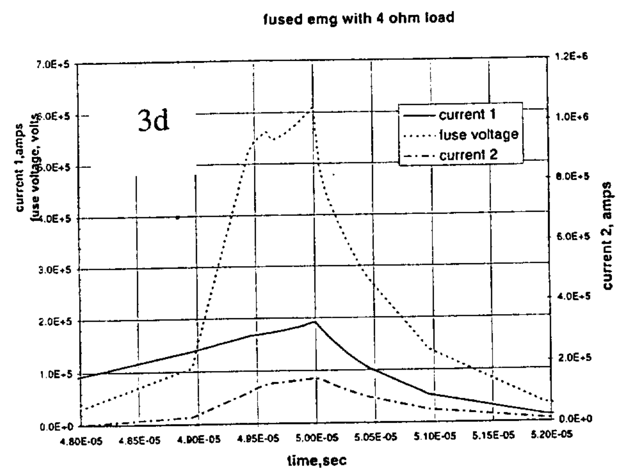


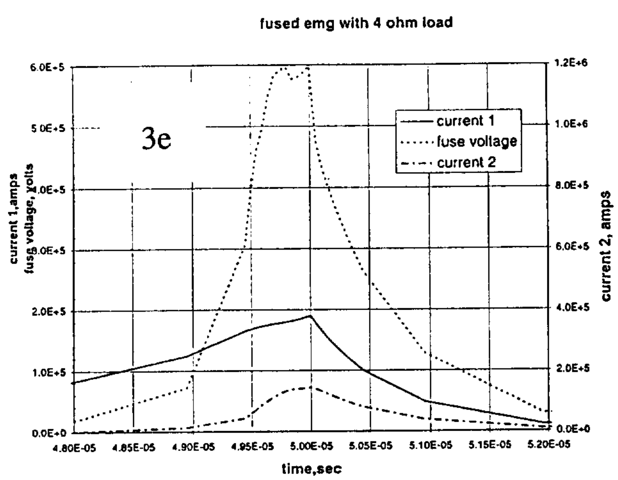
Fig.2 Resistivity vs specific energy for Al foil fuses in granular quench medium. Solid curve is from capacitor driven experimental data, e.g., as in Tucker and Toth[5]. Filled circles are from fit used in modeling. Model assumes no further increase in resistivity above 1000 $\mu\Omega$-cm.

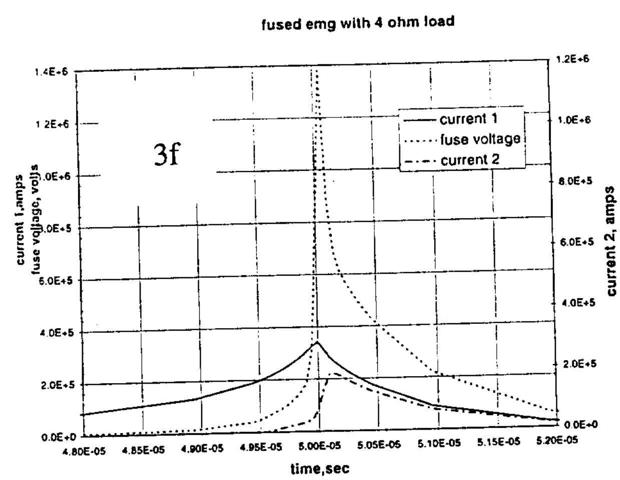

fused emg with 4 ohm load
3a
current 1
fuse voltage
current 2
current 1,amps
fuse voltage, volts
current 2, amps
time,sec

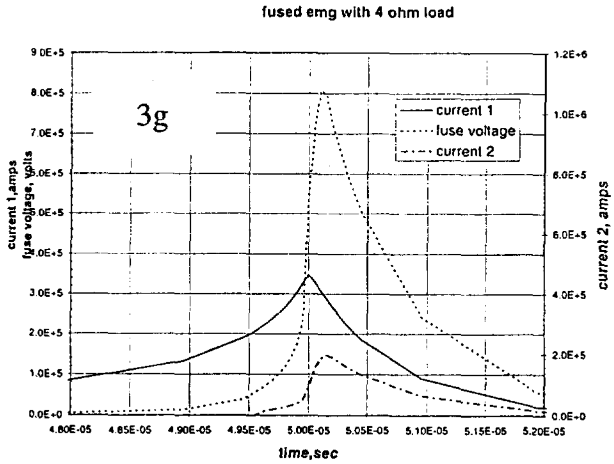

fused emg with 4 ohm load
3b
current 1
fuse voltage
current 2
current 1,amps
fuse voltage, volts
current 2, amps
time,sec


fused emg with 4 ohm load
3c
current 1
fuse voltage
current 2
current 1,amps
fuse voltage, volts
current 2, amps
time,sec


fused emg with 4 ohm load
3d
current 1
fuse voltage
current 2
current 1,amps
fuse voltage, volts
current 2, amps
time,sec


fused emg with 4 ohm load
3e
current 1
fuse voltage
current 2
current 1,amps
fuse voltage, volts
current 2, amps
time,sec


fused emg with 4 ohm load
3f
current 1
fuse voltage
current 2
current 1,amps
fuse voltage, volts
current 2, amps
time,sec



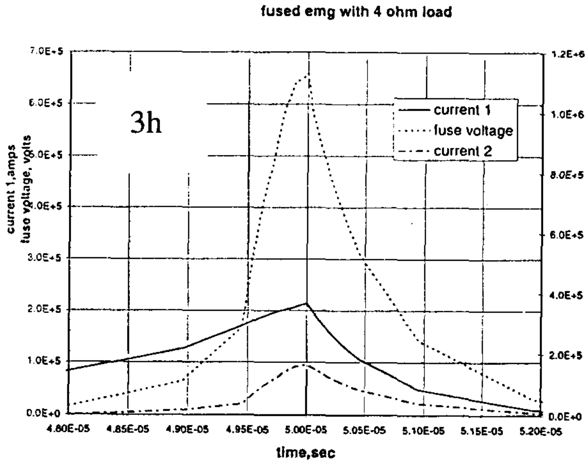


Fig.3 Generator current (current 1), load current (current 2), and fuse voltage vs time calculated numerically using circuit and elements in Fig 1. Varied element parameters and result summary are shown in Table I.

Figure	L_{go}	I_o	L_s	R_s	L_L	S_f	V_{fp}	I_{2p}	FWHM (I_2)
3a	57.μ H	10 KA	0.5μH	50 mΩ	0.5μ H	0.22x 10^{-5} m^2	1.51 MV	237KA	0.3μsec
3b	57	10	0.5	50	0.5	0.154x10^{-5}	0.669	139	0.9
3c	200μH	5KA	2μ H	50 mΩ	0.5μH	0.108x10^{-5}	1.43	218	0.6
3d	200	5	2	50	0.5	0.076x10^{-5}	0.61	146	1.5
3c	200	5	2	200	0.5	0.076x10^{-5}	0.598	144	0.9
3f	200	5	2	200	0.5	0.108x10^{-5}	1.38	188	0.45
3g	200	5	2	200	0.13	0.108x10^{-5}	0.809	197	0.45
3h	200	5	2	200	0.13	0.078x10^{-5}	0.659	163	0.85

Table I: Summary of calculated fuse sharpened explosive generator performance.

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